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Tau trigger for Higgs studies at CMS

HIGGS and SUPERSYMMETRY. Orsay 20.03.01

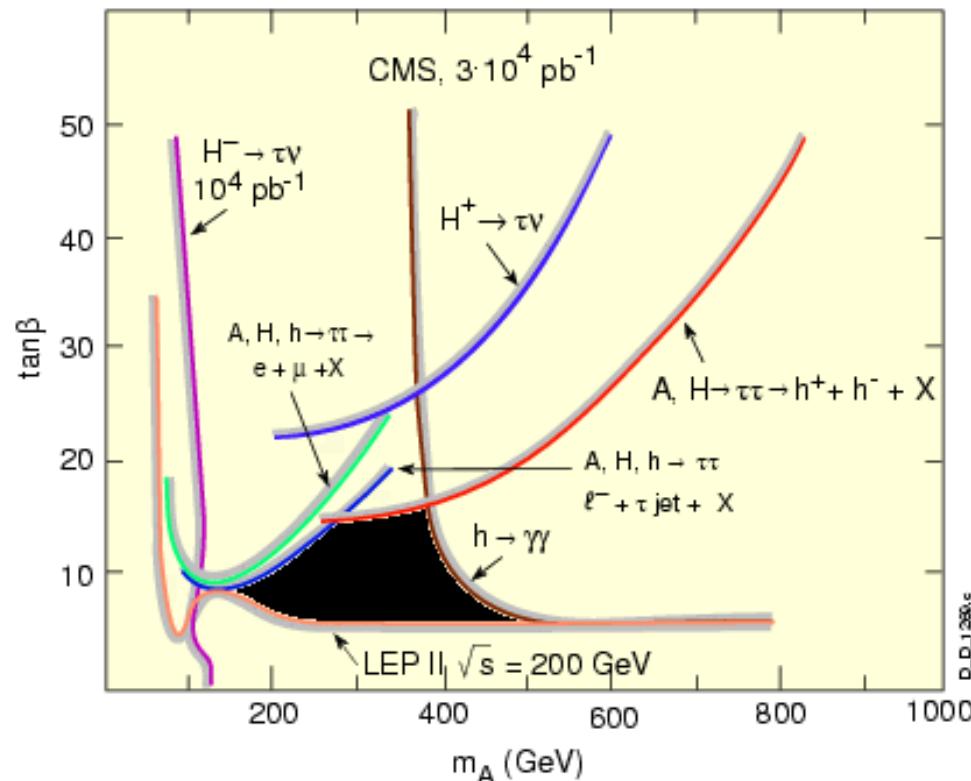
CMS Lvl-1 and High Level Tau Triggers

- motivation for Lvl-1 Tau trigger in Higgs searches
- Lvl-1 trigger performance for $H \rightarrow 2\tau$ channels
- High Level Tau triggers with calorimetry and tracker

CMS searches on $H \rightarrow 2\tau$ channels

- update on SUSY A/ $H \rightarrow 2\tau$, $M_A > 200$ GeV
- status of light Higgs in weak boson fusion

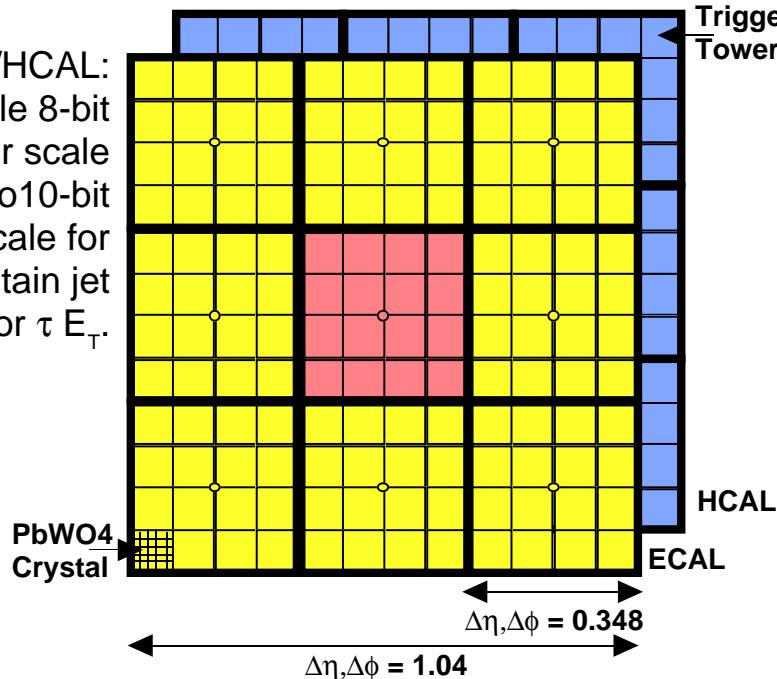
Lvl-1 Tau trigger has been adopted in CMS to enhance efficiency of low E_t τ -jets, therefore to increase trigger efficiency for $A/H \rightarrow 2\tau$ channels in $l+\tau$ -jet and 2τ -jet final states for not too heavy A/H .





Jet and Tau Algorithms

Input from E/HCAL:
Programmable 8-bit
non-linear scale
converted into 10-bit
linear scale for
sums to obtain jet
or τE_T .



Trigger Tower Active towers counted after a trigger tower level programmable threshold. τ -veto bit formed by requiring that there be no more than 2 active ECAL or HCAL towers in a 4×4 region.

Jet or τE_T

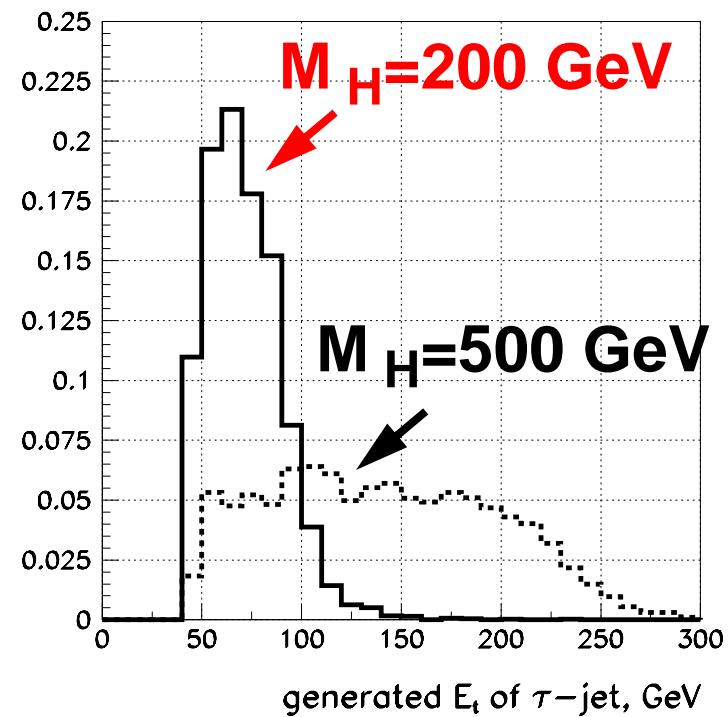
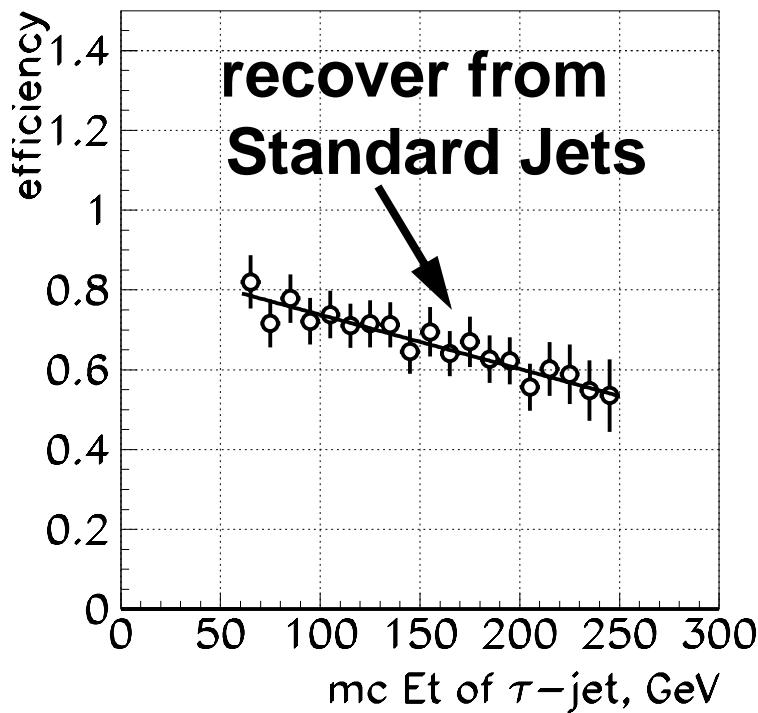
- 12x12 trigger tower E_T sums in 4×4 region steps with central region > others
 τ algorithm (isolated narrow energy deposits)

- Redefine jet as τ jet if none of the nine 4×4 region τ -veto bits are on

Output

- Top 4 τ -jets and top 4 jets in central rapidity, and top 4 jets in forward rapidity

L1 Tau Trigger gives an access to low p_t τ -jets and => to “black” hole



Triggering on SUSY Higgs into 2τ at Lvl-1

Trigger Type	Cutoff(GeV)	
	Low Lumi	High Lumi
1. Electron	20	30
2. Dielectron	10	15
3. Single Tau	80	150
4. Double Tau	60	80
5. Jet	120	250
6. DiJet	90	200
7. TriJet	70	100
8. Quadjet	50	80
9. Jet-Electron	100&10	150&15
10. Tau-Electron	65&10	90&15
11. MissEt(MET)	100	150
12. Electron-MET	10&50	15&100
13. Jet-MET	50&50	80&100
14. Sum E_T	500	1000

2 J mode

M_H Low lumi High lumi
eff. triggers **eff. triggers**

200 GeV **0.98** T, 2T, 2J, J **0.65** 2T, T
500 GeV **0.99** T,2T, J,2J **0.86** T,2T,J,2J

e+J mode

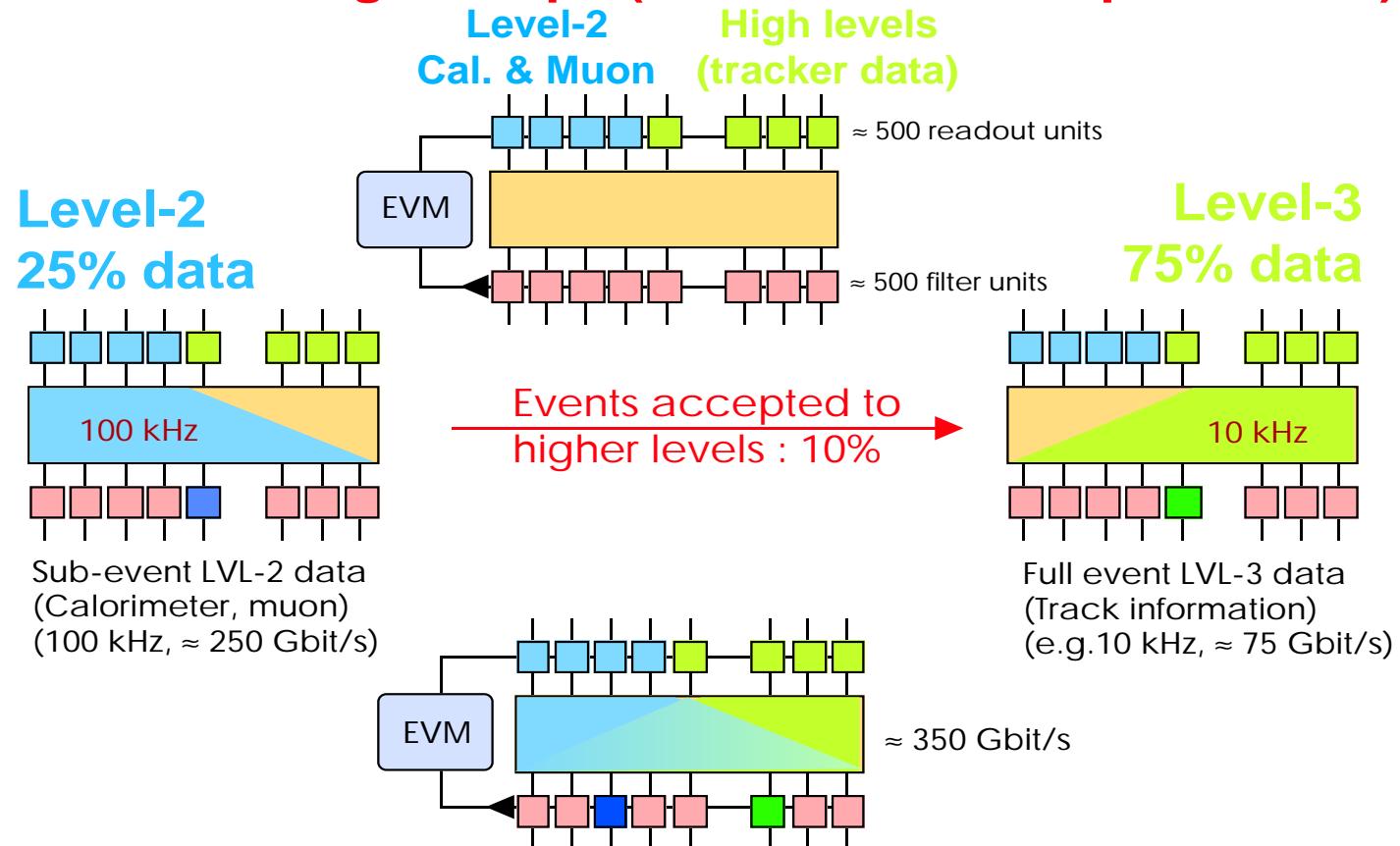
M_H eff. triggers eff. triggers
200 GeV **0.96** e,T-e,T,J-e **0.74** e, T-e

the most efficient triggers are chosen and placed in the order of descending efficiency



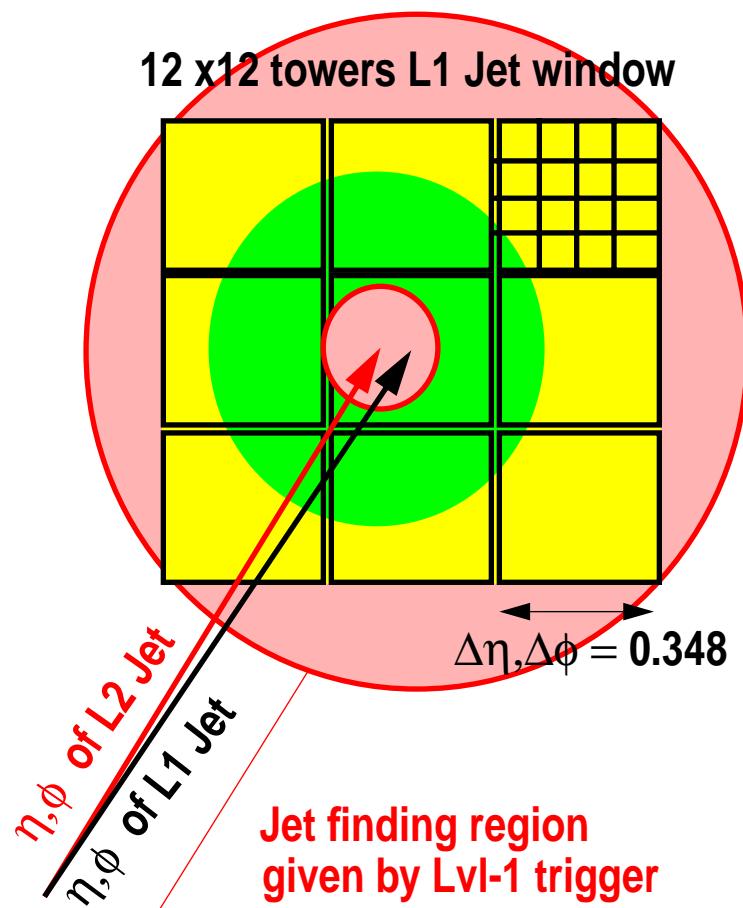
HLT: Overview (II)

Both Level-2 & Level-3 Triggers in processor farm;
Event Building in steps (reduce switch requirements)



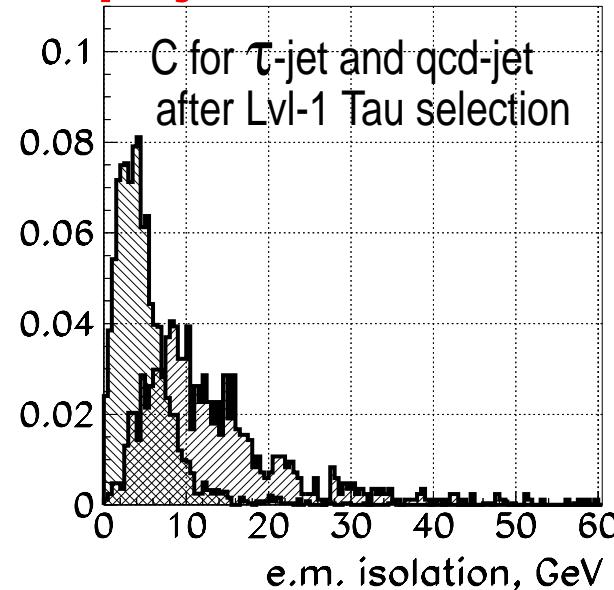


Tau identification at Lvl-2



Narrowness of τ jets :

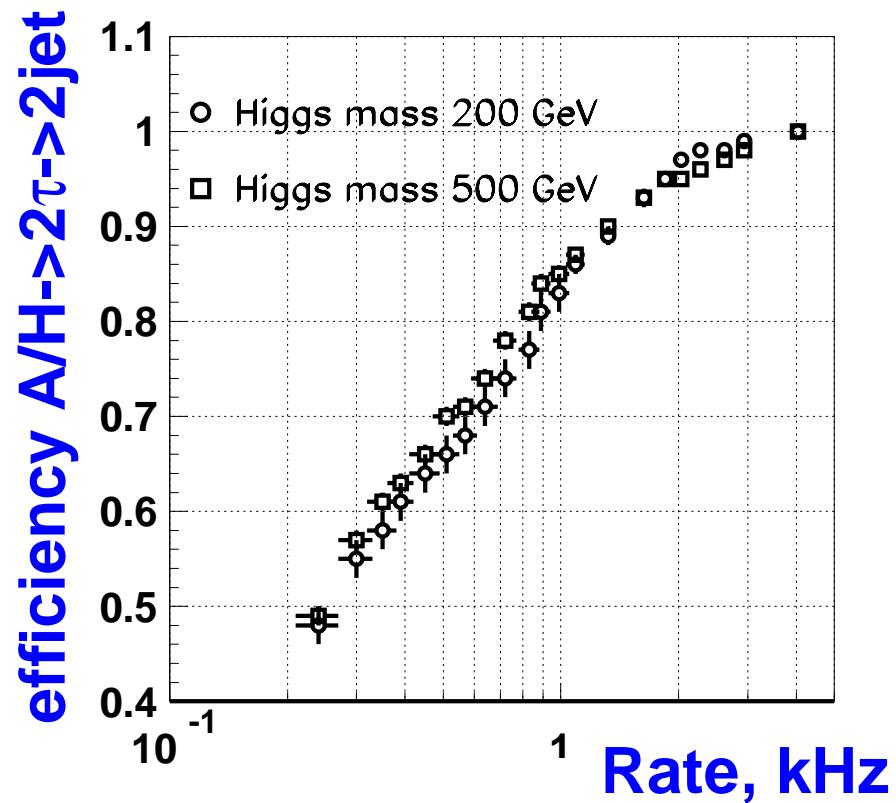
- reconstruct jet in region given by Lvl-1 trigger
- use $C = \sum E_{\text{em}}^{\text{jet}} (0.13 < R < 0.40)$
- accept jet as τ if $C < C^{\max}$





Lvl-2 Tau algorithm performance (II)

- ❑ for a 200-500 GeV Higgs, a factor 10 reduction in rate with respect to Lvl-1 implies a Lvl-2 efficiency $\sim 65\%$
- ❑ this is using only calorimeter data

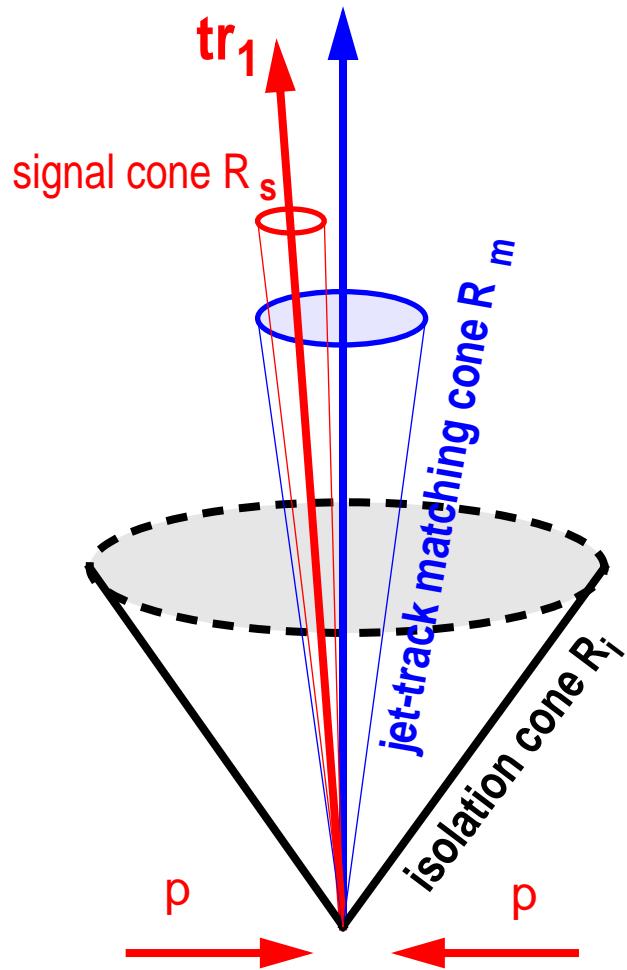


Lvl-2 Tau study is summarized in CMS Note 2000/055



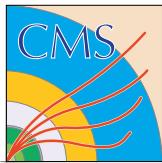
Tau identification at Lvl-3

Lvl-2 τ - jet axis



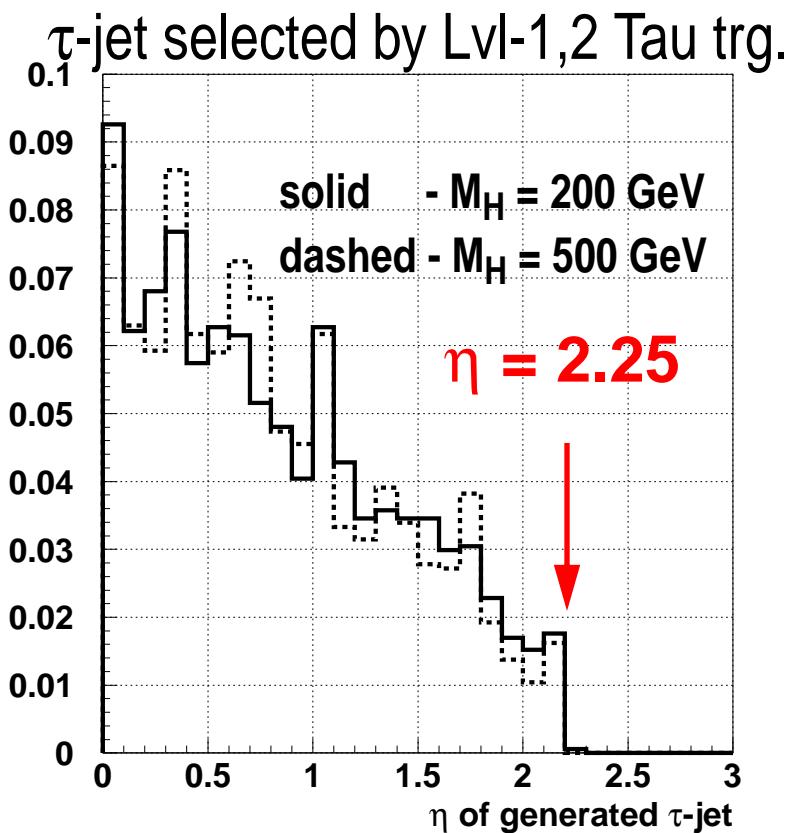
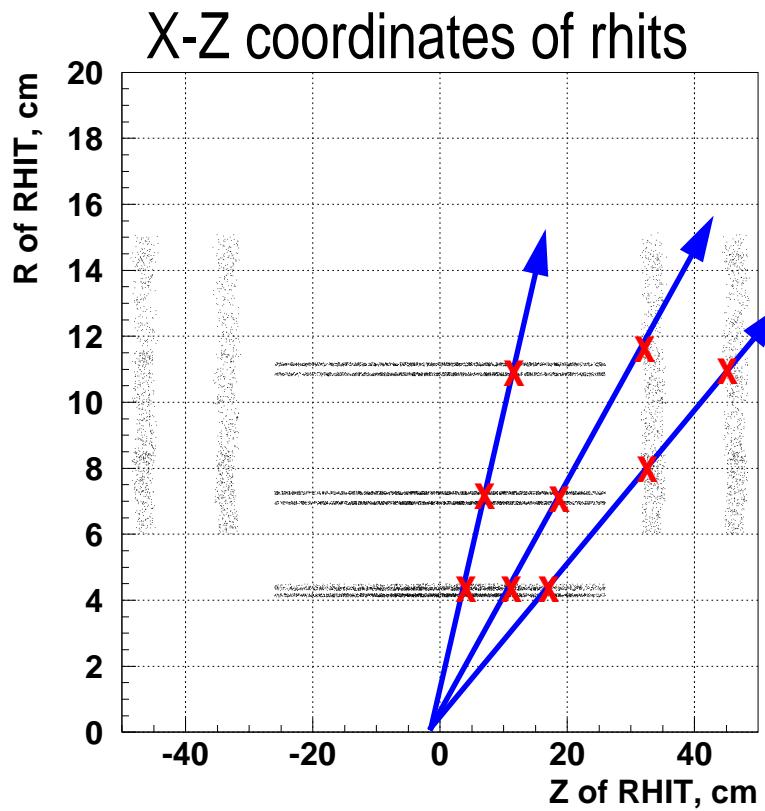
Algorithm steps

- ❑ reconstruct tracks $p_t > 1$ GeV with pixels only
resolution : $\sigma(p_t)/p_t = [3.6 + 1.7 p_t(\text{GeV})]\%$
- ❑ find primary vertices (histogramming method)
- ❑ find highest p_t track with good Lvl-2 jet matching
 $\Delta R(j - tr_1) < R_m$ (~ 0.1) , $p_t^{tr1} > p_t^m$ (~ 3 GeV),
 tr_1 defines signal primary vertex (PV)
- ❑ count number of tracks from PV in the isolation cone and signal cone :
 N_i tracks with $\Delta R(j - tr) < R_i$ (~ 0.3) ,
 N_s tracks with $\Delta R(tr_1 - tr) < R_s$ (~ 0.05) ,
 $p_t^{tr} > p_t^i$ (~ 1 GeV)
- ❑ accepts as τ if tracks found only in signal cone
 $N_s = N_i$



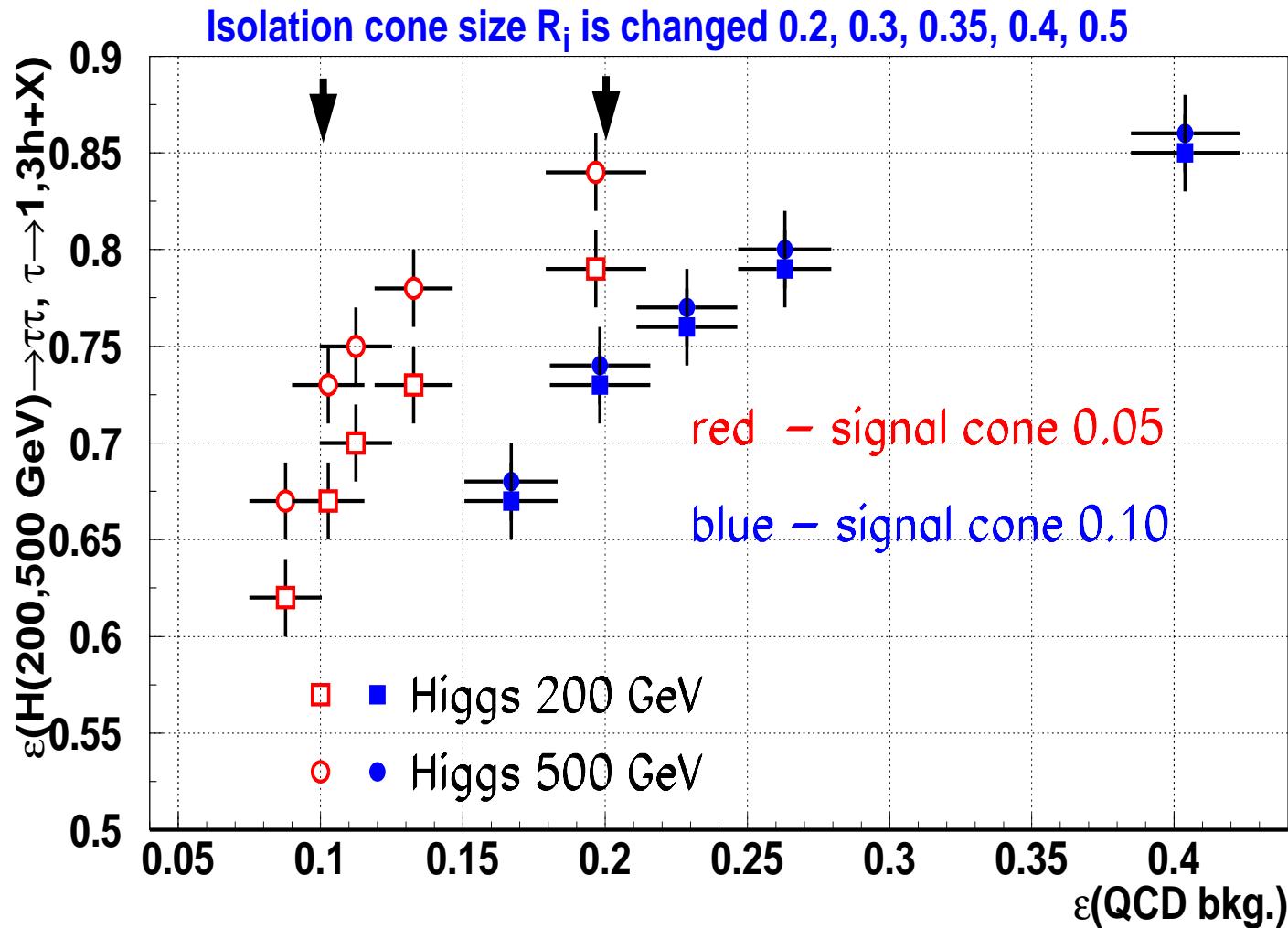
η coverage update

pixel track finder works up to $|\eta| < 2.25$





Tau vs QCD efficiency at Lvl-3 with Pixel Detector



Trigger path from Lvl-1 to tape for $A/H \rightarrow 2\tau \rightarrow 2\text{jet}$ at $L=10^{34}\text{cm}^{-2}\text{s}^{-1}$

Trigger level	QCD bkg.rate	$N(A/H)$ for 10^5pb^{-1} $M_A=500\text{ GeV}, \tan(\beta)=25$
Lvl-1, calo data	~ 4 000 ev. / s	3 337 ev.
Lvl-2, ecal data	~ 400 ev. / s	2 236 ev.
Lvl-3, pixels only	~ 40 (80) ev. / s	1 677 ev.
Lvl-3, regional tracking & 2-nd τ -jet analysis		work is in progress



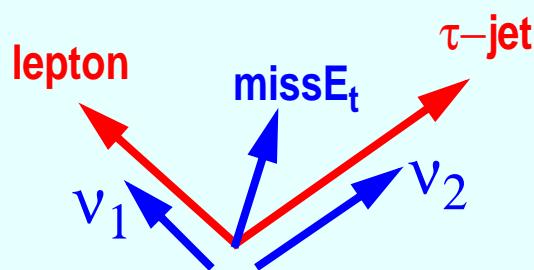
Update on $H_{\text{SUSY}} \rightarrow 2\tau$ channels

- current work with full simulation and OO/c++ reconstruction software on :
 - trigger path optimization (previous slides)
 - Higgs mass reconstruction
 - b-tagging efficiency for $gg \rightarrow bbH$ selection

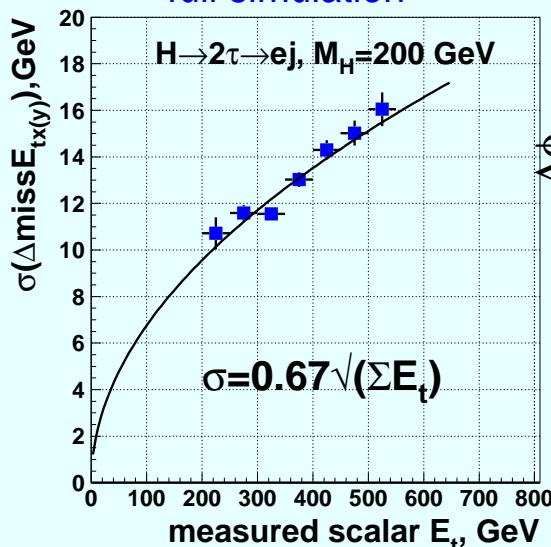
- update on $H_{\text{SUSY}} \rightarrow 2\tau \rightarrow 2$ jet channel
 - jet fragmentation effects on QCD rejection
 - miss E_t and b-tagging
 - attempt to include 3 prong τ - jets
 - cross sections and br. ratios with SPYTHIA

Mass Reconstruction in H/A-> $\tau\tau$ ->lept. + τ -jet

$$M_\tau \ll E_t^\tau$$



missE_t resolution with full simulation



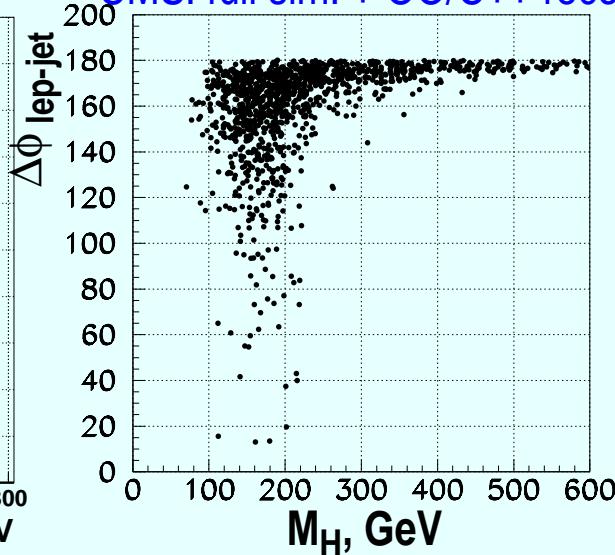
$$E\nu_1 x_1 + E\nu_2 x_2 = E_x^{\text{miss}}$$

$$E\nu_1 y_1 + E\nu_2 y_2 = E_y^{\text{miss}}$$

$$\sigma(M_H) \sim \sigma(E_t^{\text{miss}}) / \sin(\Delta\phi)$$

back-to-back is the worst case for the mass reconstruction

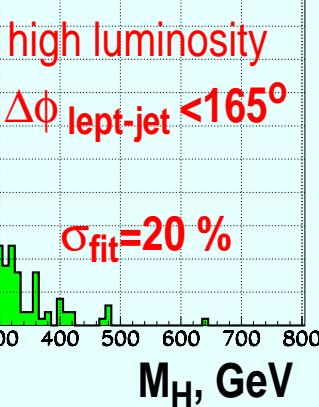
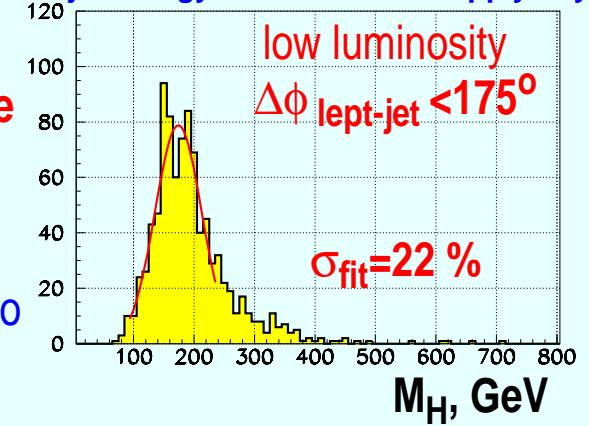
M_H - $\Delta\phi$ lept-jet correlation
CMS. full sim. + OO/C++ reco



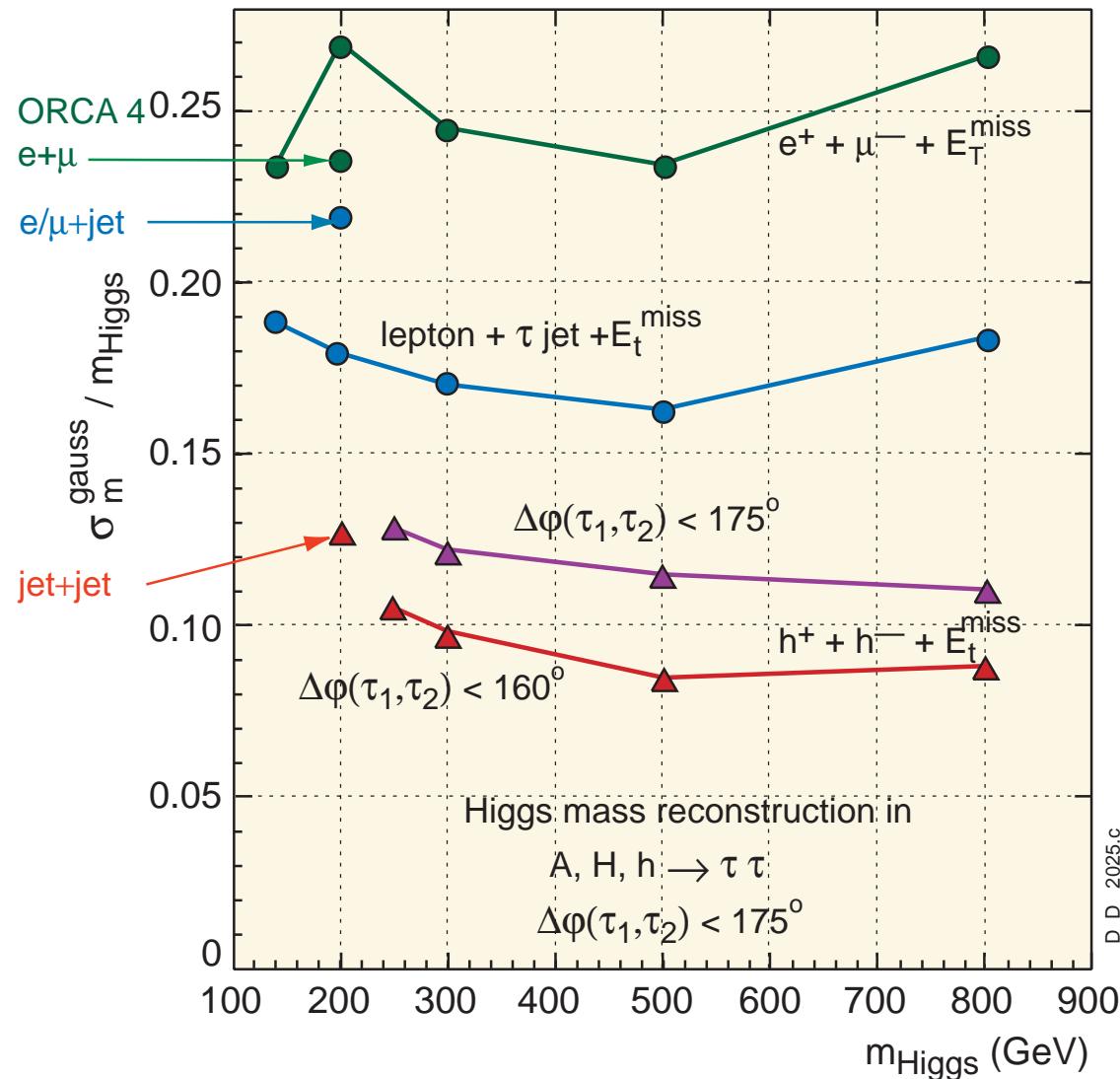
qq->bbH **SUSY**, $M_H = 200 \text{ GeV}$

CMS. full sim. + OO/C++ reco

no jet energy corrections are applied yet

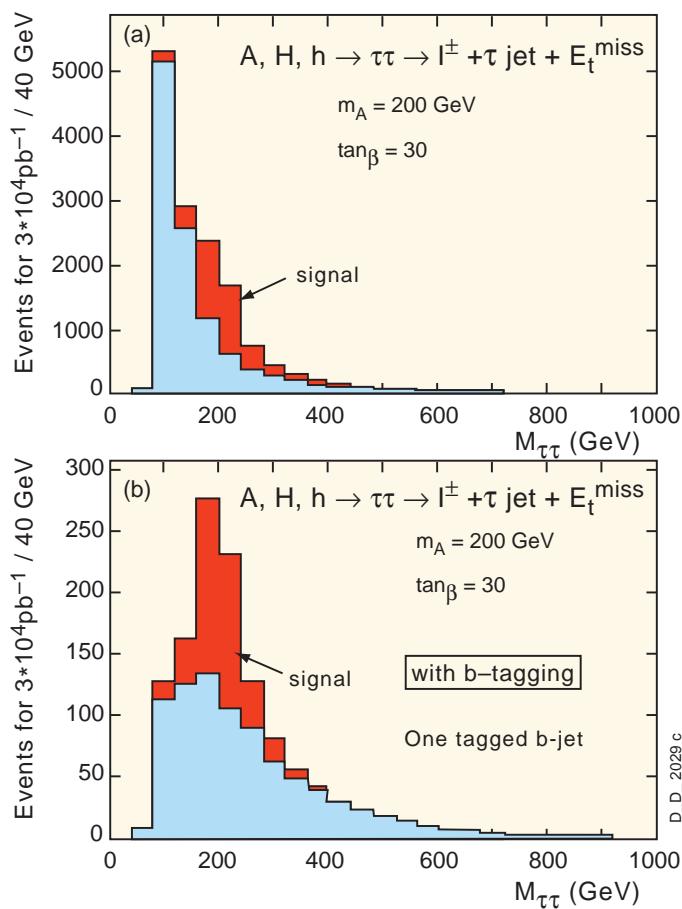


Higgs mass resolution in $H \rightarrow \tau^+ \tau^-$



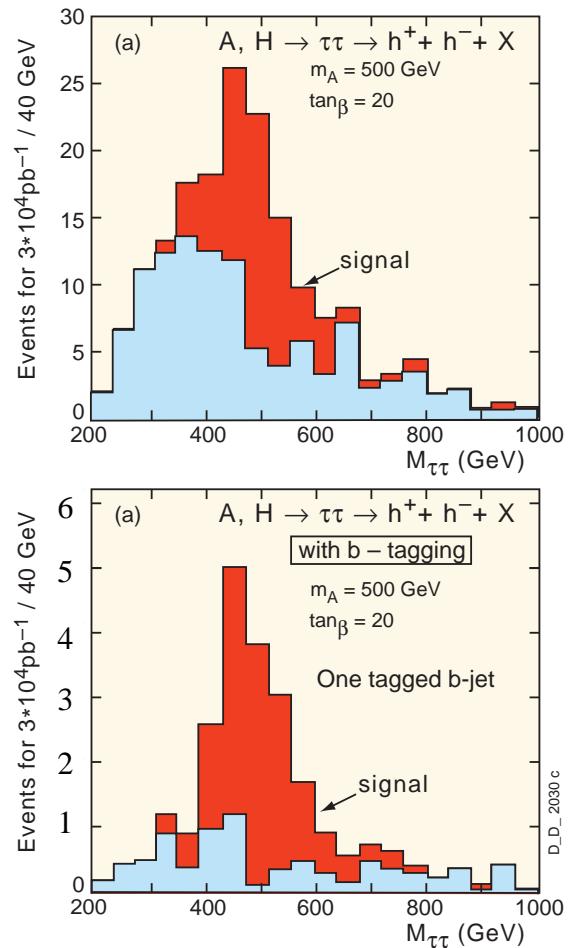
H_{SUSY} -> $\tau\tau$ -> $I^\pm + h^- + X$

Events selected as : $P_t^{\text{jet}} > 40 \text{ GeV}$,
 $P_t > 15 \text{ GeV}$, $\Delta\phi(jl) < 175^\circ$, $E_t^{\text{miss}} > 20 \text{ GeV}$

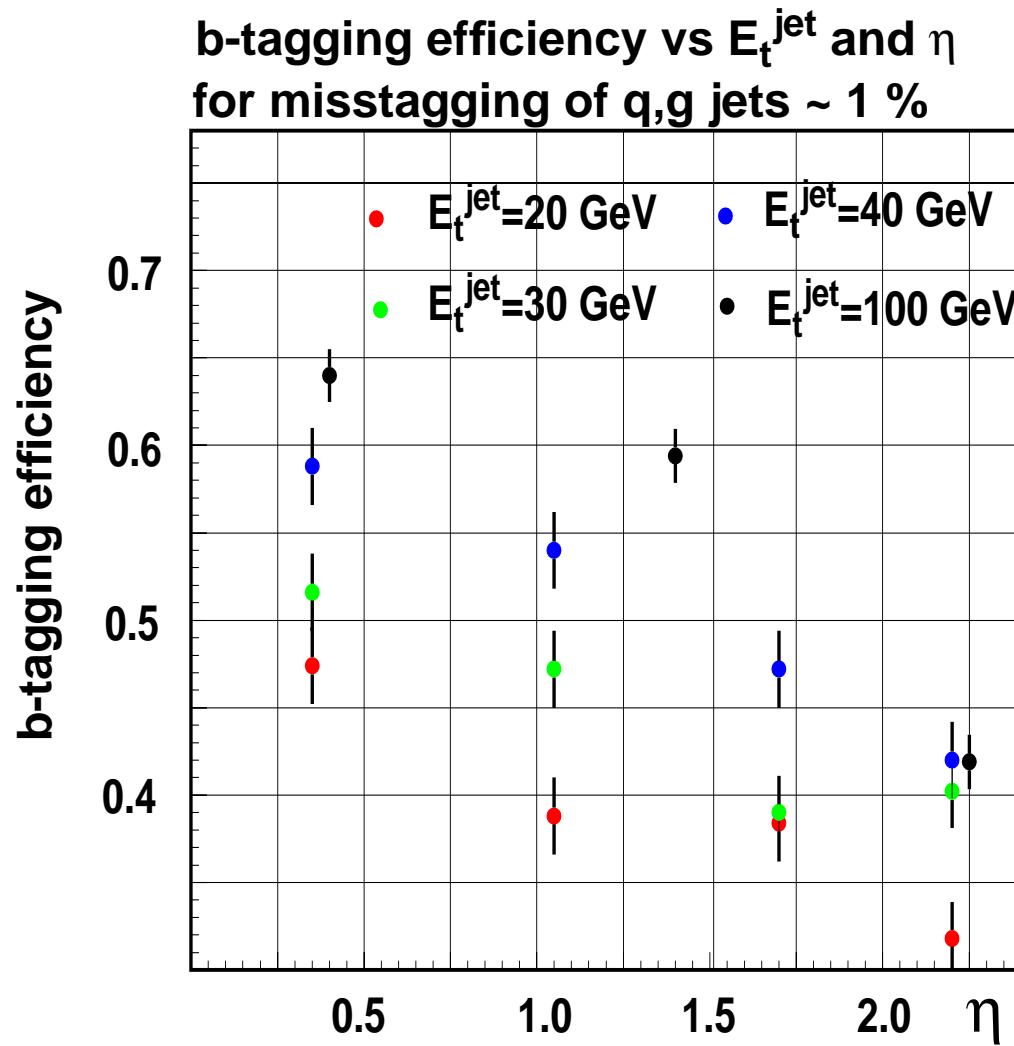


H_{SUSY} -> $\tau\tau$ -> $h^+ + h^- + X$

Events selected as: $E_t^{\text{jet}} > 60 \text{ GeV}$
 $p_t^h > 40 \text{ GeV}$, $\Delta\phi(jj) < 175^\circ$, $E_t^{\text{miss}} > 40 \text{ GeV}$



CMS b-tagging with full detector simulation



H->2 τ ->2jets : Jet fragmentation and QCD rejection factor

QCD jet is accepted as τ -jet if :

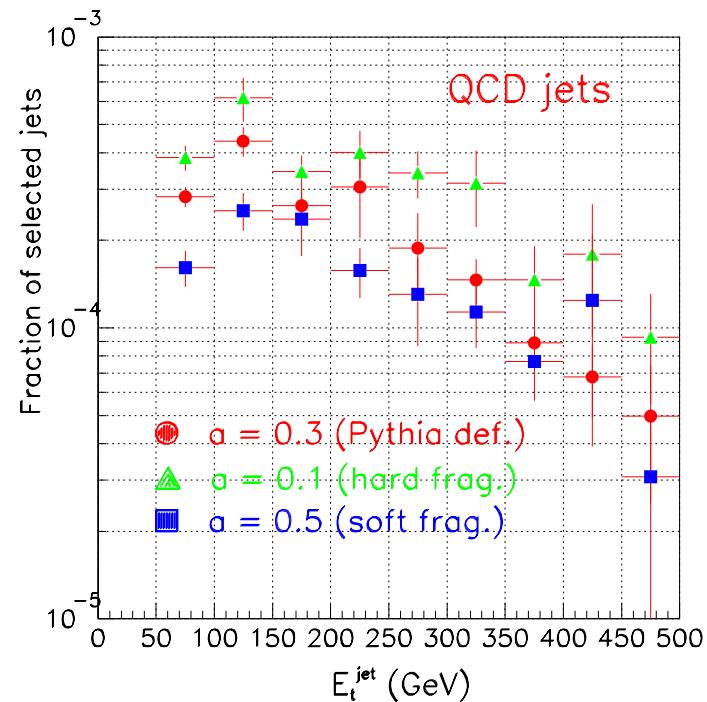
- $E_t^{\text{jet}} > 60 \text{ GeV}$
- 1 track of $p_t > 40 \text{ GeV}$ in $\Delta R_{j\text{tr}} < 0.1$
- 0 tracks of $p_t > 1.5 \text{ GeV}$ in $0.1 < \Delta R_{j\text{tr}} < 0.4$

Check how much QCD rejection factor depends on parameter a in Lund fragmentation function

$$f(z) \sim z^{-1} (1-z)^a \exp(-bm_T^2/z)$$

$a=0.3$ (*pythia default*), $b=0.58 \text{ GeV}^2$

uncertainty is less than 1.5



QCD rejection with different fragmentation

H->2 τ ->2jets : if 3 prong τ - jets can be included ?

- increase of the signal by factor ~ 1.7
- qcd 2j background may grow by factor ~ 2-3

in the figure

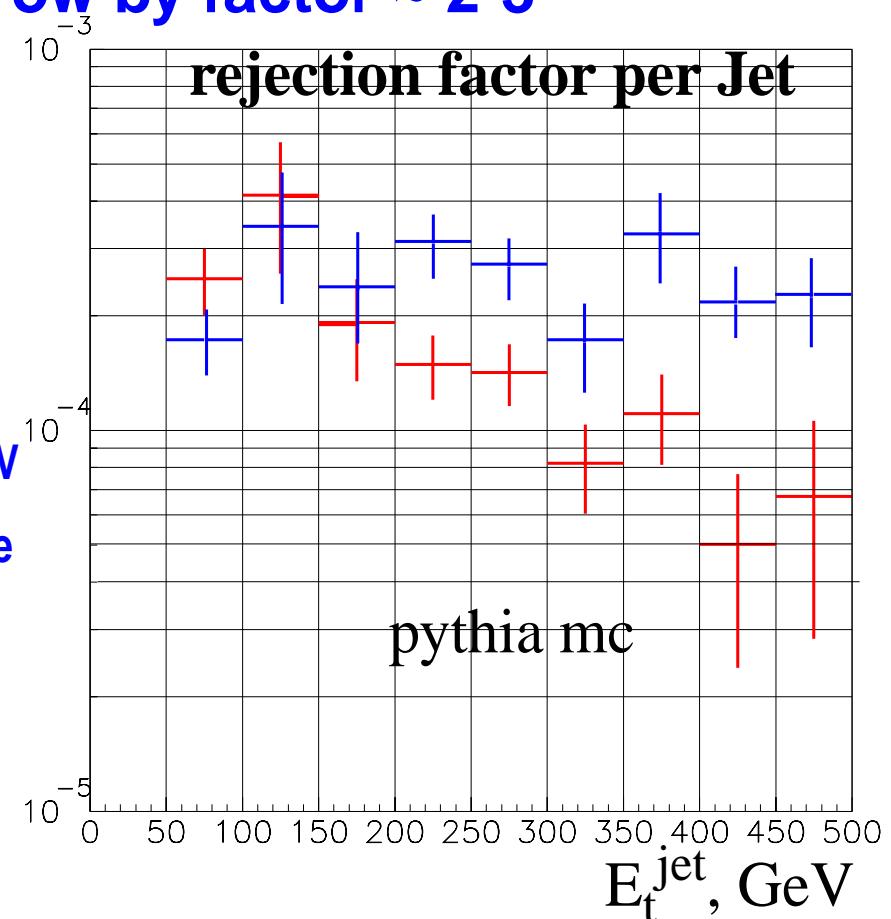
red - 1 track of $p_t^h > 40$ GeV in signal cone

no other tracks of $p_t > 1.5$ in isol. cone

blue - 1 or 3 tracks in signal cone, $p_t^{\max} > 40$ GeV

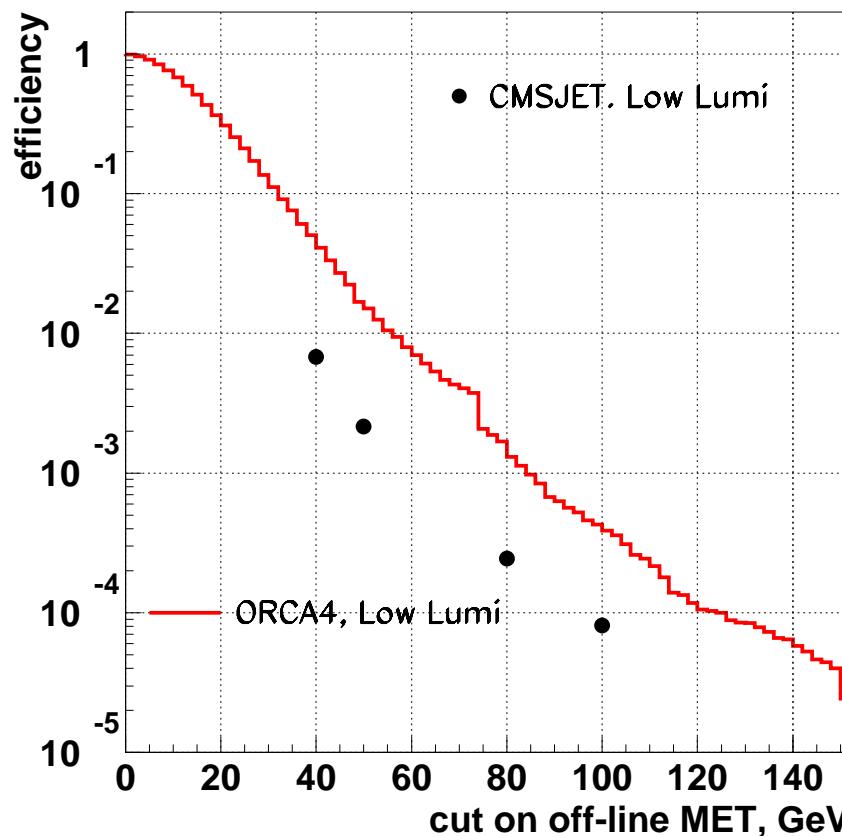
no other tracks of $p_t > 1$ GeV in isol. cone

recovery with τ - vertex ?



H->2 τ ->2jets : E_t^{miss} rejection factor with full simulation

missing E_t rejection factor for QCD bkg. with 2 jets of $E_t^{\text{jet}} > 60 \text{ GeV}$



CMSJET doesn't include non linearity effects of calorimetry

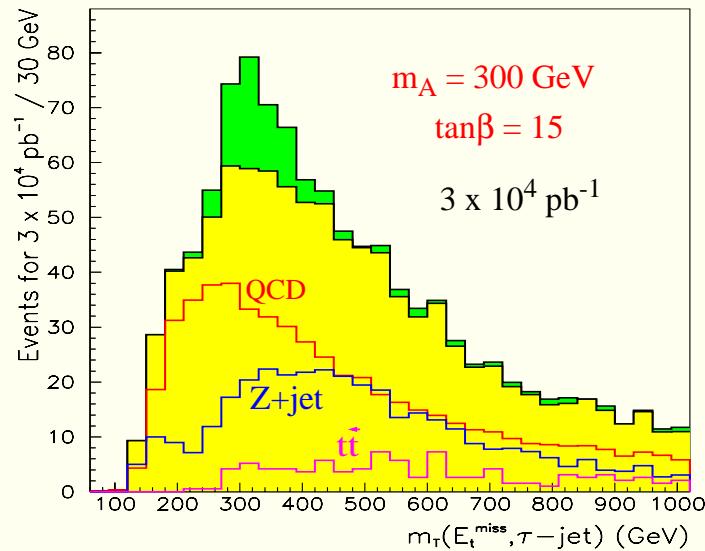
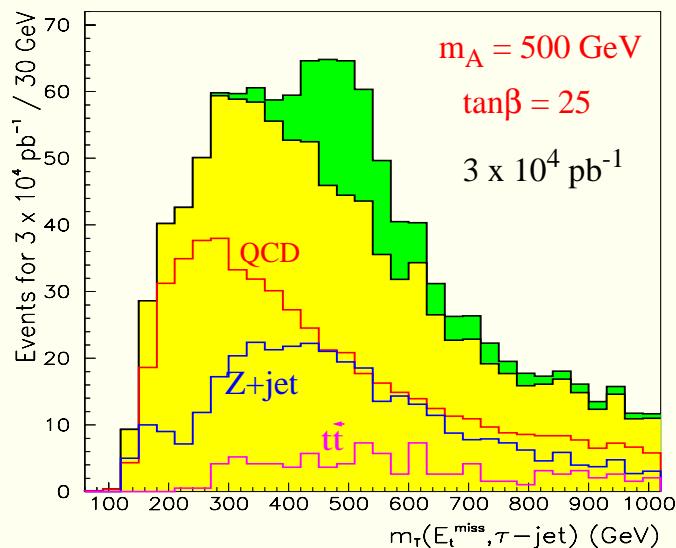
ORCA (oo/c++ reconstruction)
still doesn't make proper corrections for this effect
(work in progress)

- “true” rejection factor of $E_t^{\text{miss}} > 40 \text{ GeV}$ is between ~ 20 and 100
- b-tagging provides enough rejector factor even without E_t^{miss} cut

$A, H \rightarrow \tau\tau \rightarrow h^+ + h^- + E_t^{\text{miss}} + X$

with **hard QCD jet fragmentation** and with
 E_t^{miss} rejection factor for QCD ~ 20 (from ORCA)

$a = 0.1$ in the symmetric Lund fragmentation function



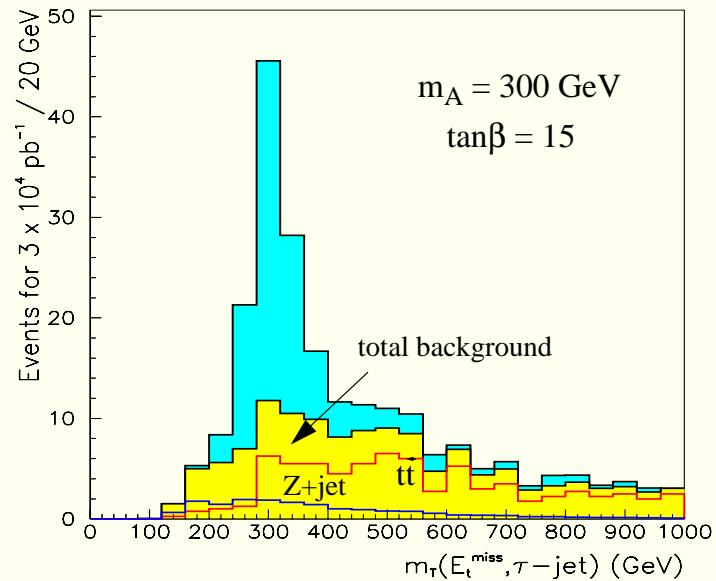
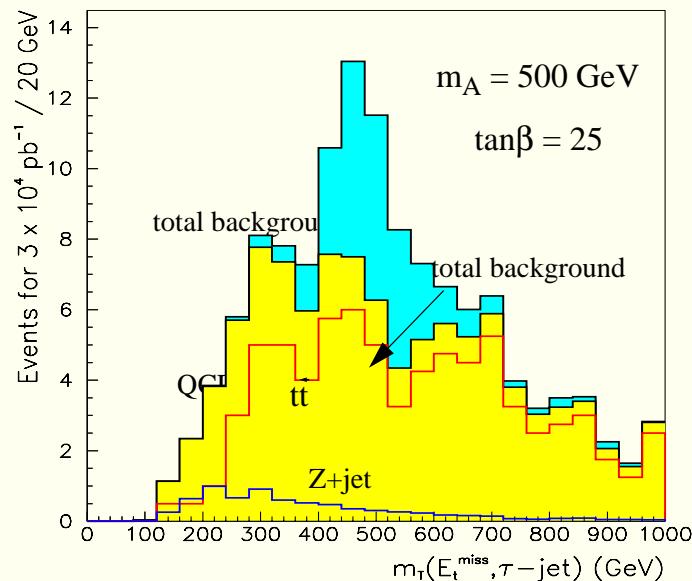
$E_t^{\tau\text{-jet}} > 60 \text{ GeV}, p_t^h > 40 \text{ GeV}$ (isolated), $E_t^{\text{miss}} > 40 \text{ GeV}, \Delta\phi(j_1, j_2) < 175^\circ$

$$A, H \rightarrow \tau\tau \rightarrow h^+ + h^- + E_t^{\text{miss}} + X$$

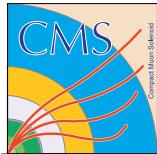
Signal over background with **b-tagging** and for $3 \times 10^4 \text{ pb}^{-1}$

No E_t^{miss} cut, at least one jet with $E_t > 30 \text{ GeV}$ for b-tagging

b-tagging efficiency assumed: 40% for signal, 60% for $t\bar{t}$, 2% for Z+jet and QCD



$$E_t^{\tau\text{-jet}} > 60 \text{ GeV}, p_t^h > 40 \text{ GeV} \text{ (isolated)}, \Delta\phi(j_1, j_2) < 175^\circ$$



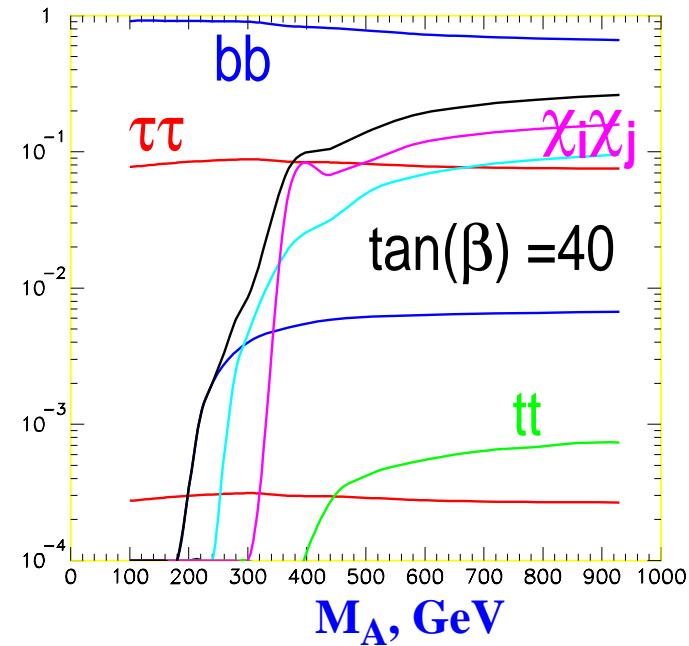
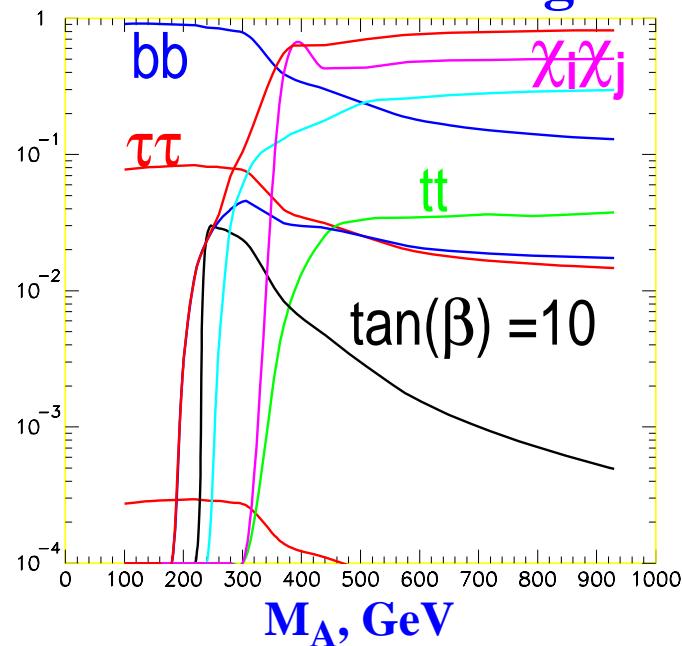
Cross sections and br. ratios with SPYTHIA, no mixing.

LEP no mixing : $M_{\text{SUSY}}=1 \text{ TeV}$, $\mu=-200 \text{ GeV}$, $M_2=200 \text{ GeV}$, $m_g=0.8 M_{\text{SUSY}}$, $X_t=0$

cross sections for $\text{pp} \rightarrow A + X$

$M_A, \tan(\beta)$	(300,15)	(500,25)	(800,45)
SPYTHIA	7.6 pb	2.1 pb	0.6 pb
PYTHIA5.7	8.6 pb	3.1 pb	1.3 pb

branching ratios for H^0 with SPYTHIA

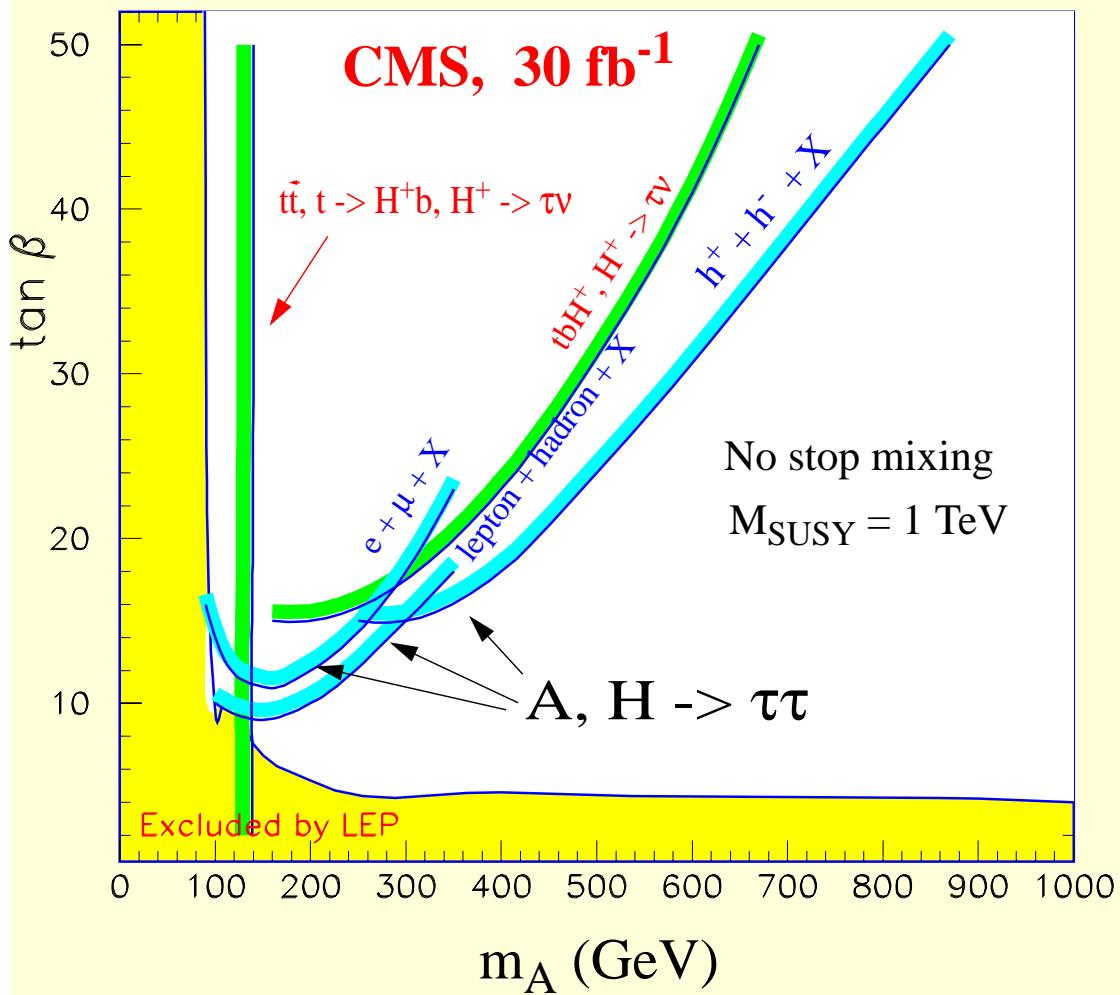


Events for signal and background with selection cuts

for $3 * 10^4 \text{ pb}^{-1}$

$m_A, \tan\beta$	(200,15)	(300,15)	(500,25)	(800,40)
Signal	49	56	87	48
Z, γ^*	36	71	111	54
QCD	7	19	34	20
$t\bar{t}$	2	9	19	9
W+jet	-	2	10	10
Total BG	45	101	174	93
S / \sqrt{B}	7.3	5.6	6.6	5.0

5 σ significance contours for heavy SUSY Higgses



weak boson fusion channels

indirect measurement of the light Higgs width ($<< 1 \text{ GeV}$) is possible with accuracy 10-20 % combining following $\text{qq} \rightarrow \text{qqH}$ channels :

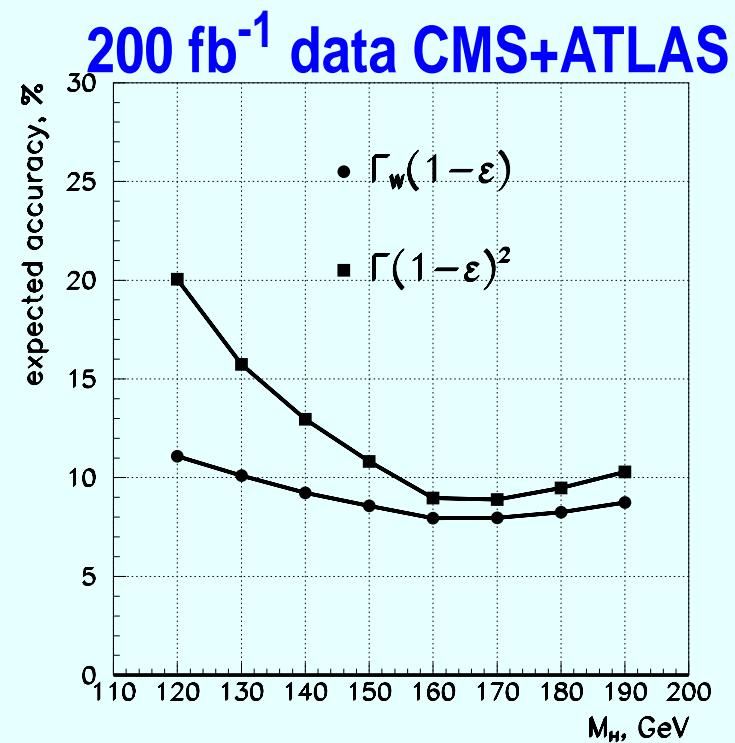
1. $H \rightarrow 2\tau, e/\mu + J, e + \mu$

2. $H \rightarrow WW \rightarrow 2l$

3. $H \rightarrow 2\gamma$

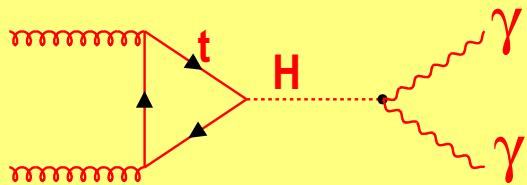
+ 4) $gg \rightarrow WW \rightarrow 2l$

coupling measurement



D.Zeppenfeld, R.Kinnunen, A.Nikitenko, E.Richter-Was, Phys.Rev.,D62(2000) pp13009

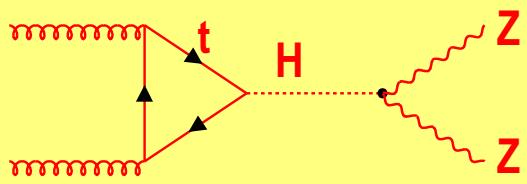
$gg \rightarrow H \rightarrow \gamma\gamma$



$M_H < 150 \text{ GeV}$

$$\sim \Gamma_g (\Gamma_\gamma / \Gamma) = Y_\gamma$$

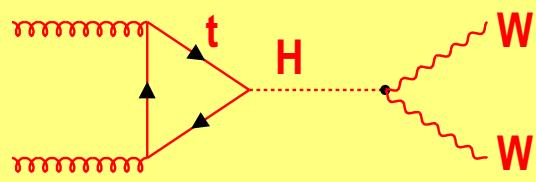
$gg \rightarrow H \rightarrow ZZ \rightarrow 4\text{lept}$



$M_H > 120 \text{ GeV}$

$$\sim \Gamma_g (\Gamma_Z / \Gamma) = Y_Z$$

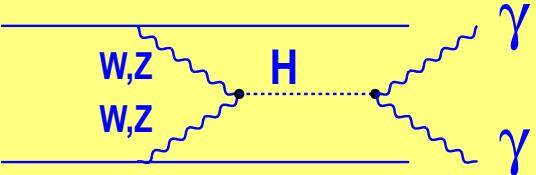
$gg \rightarrow H \rightarrow WW \rightarrow 2\text{lept}$



$M_H > 120 \text{ GeV}$

$$\sim \Gamma_g (\Gamma_W / \Gamma) = Y_W$$

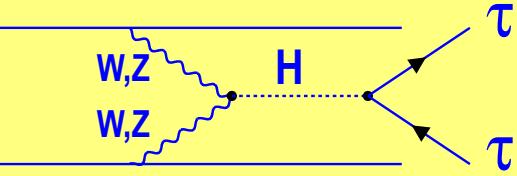
$qq \rightarrow qqH, H \rightarrow \gamma\gamma$



$M_H < 150 \text{ GeV}$

$$\sim \Gamma_W (\Gamma_\gamma / \Gamma) = X_\gamma$$

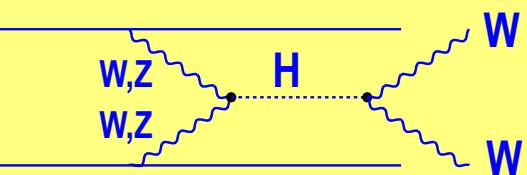
$qq \rightarrow qqH, H \rightarrow \tau\tau$



$100 < M_H < 150 \text{ GeV}$

$$\sim \Gamma_W (\Gamma_\tau / \Gamma) = X_\tau$$

$qq \rightarrow qqH, H \rightarrow WW \rightarrow 2\text{lept}$



$M_H > 120 \text{ GeV}$

$$\sim \Gamma_W (\Gamma_W / \Gamma) = X_W$$

Triggering on light Higgs in $qq \rightarrow qqH$ at Lvl-1

Trigger Type	Cutoff(GeV)	
	Low Lumi	High Lumi
1. Electron	20	30
2. Dielectron	10	15
3. Single Tau	80	150
4. Double Tau	60	80
5. Jet	120	250
6. DiJet	90	200
7. TriJet	70	100
8. Quadjet	50	80
9. Jet-Electron	100&10	150&15
10. Tau-Electron	65&10	90&15
11. MissEt(MET)	100	150
12. Electron-MET	10&50	15&100
13. Jet-MET	50&50	80&100
14. Sum E_T	500	1000

e+J mode
 M_H Low lumi High lumi
eff. triggers eff. triggers
135 GeV 0.97 e,T-e,T,J-e 0.75 e,T-e,J-e

the most efficient triggers are chosen and placed in the order of descending efficiency

cmsjet simulation

data for $M_H=135$ GeV	H-> $\tau\tau$ ->lj	QCD Z+2j*	EW Z+2j**	W+3j	bb+2j
cross-sect x Br(Z->2 τ /W->l ν)	0.1715	1.044	0.314/0.036	5180	
$p_t^l > 14$ GeV, $ \eta < 2.4$. MC $p_t^{\tau,j} > 20$ GeV, $ \eta < 2.4$ MC	0.364	0.314	0.283/0.343	0.616	
tracker lep isol + $p_t^l > 15$ GeV	0.873	0.906	0.939/0.930	0.88	
calo lepton isolation	0.915	0.954	0.939/0.967	0.91	
≥ 3 jets, $E_t > 30$ GeV, $ \eta < 4.5$	0.451	0.363	0.665/0.601	0.04	
τ -jet association(MC)	0.886	0.867	0.769/0.866	0.0019	
$\eta_j \text{ min} + 0.7 < \eta_{l,\tau,j} < \eta_j \text{ max} - 0.7$ $\eta_j \text{ min } \eta_j \text{ max} < 0$	0.587	0.757	0.527/0.559	0.20	
$ \eta_j \text{ max} - \eta_j \text{ min} > 4.4$	0.718	0.867	0.521/0.647	0.48	
$M_{JJ} > 1$ TeV	0.635	0.455	0.708/0.690	0.34	
$m_t(l, p_t^{\text{miss}}) < 30$ GeV	0.764	0.794	0.852/0.759	0.16	
$0 < x_{t1} < 0.75$, $0 < x_{th} < 1$	0.666	0.623	0.639/0.680	0.37	
M_H window 30 GeV	0.770	0.047	0.026/0.228	0.05	
P_{surv} mini jet veto from D.Z.	0.87	0.28	0.80	0.28	0.28
N event for 30 fb^{-1}	6.7 +0.3	0.63+-0.10	0.29 / 0.45 0.74+-0.08	0.14+-0.05	-
D.Z. estimates	6.2		1.1		

*D.Zeppenfeld ME element +pythia , $E_t^j > 20$ GeV, $|\eta| < 5.35$, $M_Z > 70$ GeV, $M_{JJ} > 700$ GeV, $|\Delta\eta_{JJ}| > 4.2$, $p_t^\tau > 20$ GeV

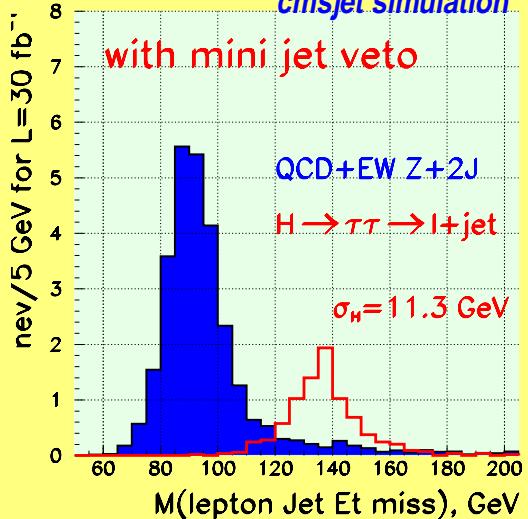
** EW Z+2J - generated by S.Ilyin with comhep, cteq4m, $E_t^j > 20$ GeV, $|\eta| < 5$, $80 < M_Z < 100$ GeV / $M_Z > 100$ GeV, $M_{JJ} > 500$ GeV
eff. of tau-id = 0.32, tau/jet missidentification = 0.0019 , eff lepton reco = 0.90



S. Ilyin, A. Nikitenko, D. Zeppenfeld
SM $qq \rightarrow qqH, H \rightarrow 2\tau \rightarrow l + j$

Preliminary results for low luminosity

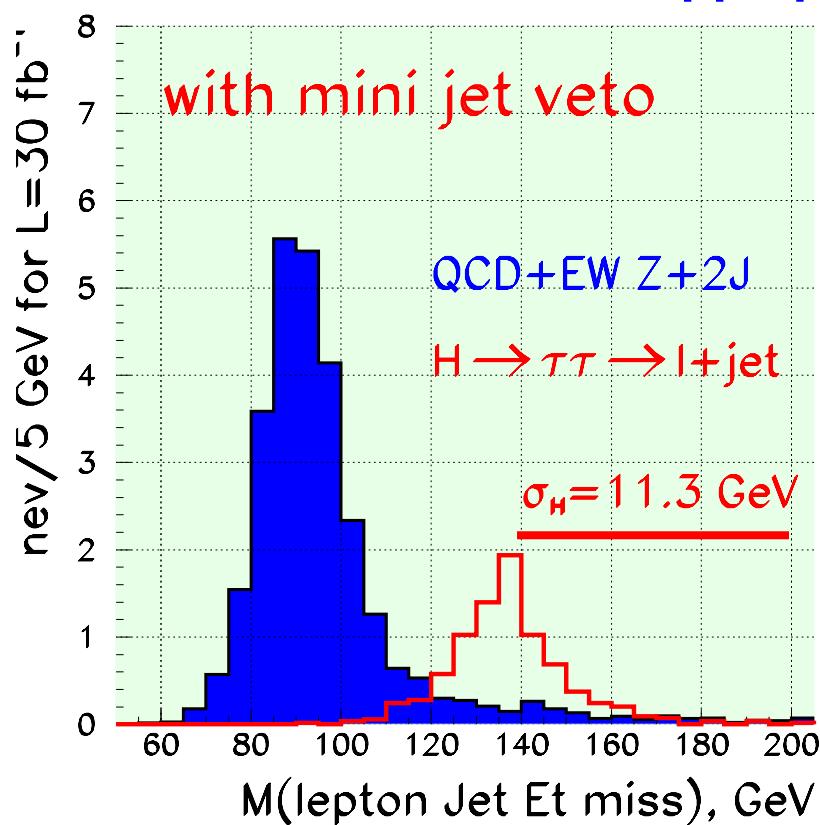
cmsjet simulation



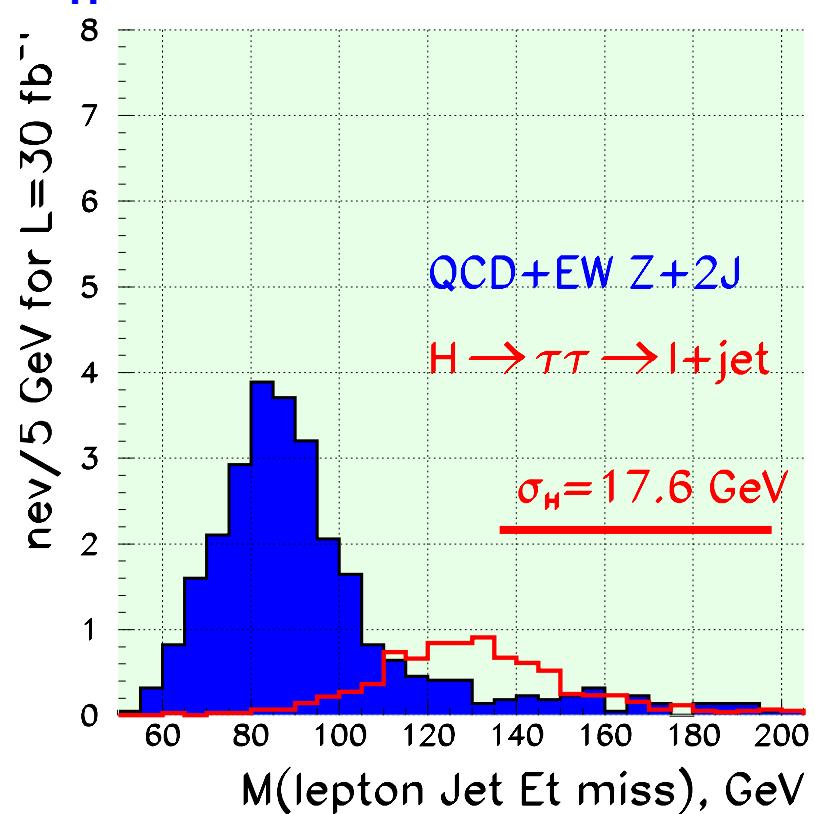
Data for 30 fb^{-1} at low luminosity running

Mass, GeV	115	125	135	145
$\sigma, \text{ pb}$	4.49	4.15	3.81	3.57
Br, \%	7.2	6.1	4.5	2.6
S	12.6	9.9	6.7(6.2)	3.6
B	5.5	2.3	1.5(1.1)	1.1

CMSJET fast simulation



full simulation and OO/c++ reco



Work is going on defining proper ecal + hcal calibration in ORCA to get rid of not linearity effects in missing E_t and jet measurement

Summary

- ❑ Lvl-1 Tau trigger is a vital element of CMS calorimeter trigger for effective search of $A/H \rightarrow 2\tau$ with hadronic τ - decays
- ❑ High Level Tau trigger algorithms with calorimeter and tracker data show a good performance for further selections of $H \rightarrow 2\tau$ channels
- ❑ detailed simulations confirm earlear CMS results for $A/H \rightarrow 2\tau$ channels on reach in M_A - $\tan(\beta)$
- ❑ work in progress to imprive observability of light Higgs in $qq \rightarrow qqH$, $H \rightarrow 2\tau \rightarrow l + jet$